Sulphur Mining in Poland

Leszek Preisner

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Foreword

As the world's largest exporter of sulphur (and second-largest producer), Canada has a keen interest in the activities of other producers of elemental sulphur around the globe. The second-largest exporter is Poland, a country now in the process of reforming its economic activities to permit it to participate more widely in free-market trading, and rationalizing its industries to make them more competitive. This paper provides information about Poland's sulphur industry, its history, its present condition, and its potential that will be useful in gauging the potential impact of Polish sulphur production and exports on world markets in the future.

It is impossible to describe adequately to a westerner the sorts of constraints under which Dr. Preisner laboured to produce the study. Suffice it to say, we are grateful for his perseverence and for his contribution to our understanding of the Polish sulphur industry.

Michel Prud'homme of Energy, Mines and Resources Canada has been generous in his help in obtaining up-to-date statistics for the recent years, when Polish research institutions were restricted in their ability to purchase foreign journals and publications.

The views expressed are those of the author and do not necessarily represent those of the Centre or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

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1. Introduction

Sulphur[1] has been mined from shallow, easily accessible deposits in southeastern Poland since the 15th century, mostly near Kraców (see Figure 1). Until the 19th century, the 200 thousand tonnes mined in Poland met the entire European demand, but Sicilian production thereafter dominated the European market. Although Poland is one of the oldest sulphur-producing countries in the world, the sulphur-mining industry is one of the youngest branches of its contemporary mining industry, having been revived and rapidly developed over the past 35 years.

A geological reappraisal of native sulphur deposits in Poland began as part of a search for raw minerals needed to restore the national economy after World War II. High-grade deposits of native sulphur were discovered in 1953 – a turning point in applied geology and in Polish sulphur mining – as a result of a geological exploration program carried out by Professor Stanislaw Pawlowski of the Geological Institute of Warsaw.

Figure 2 represents sulphur mining activities in Poland from 1415 to 1990. Dynamic growth of sulphur mining development began in 1954 when the first part of the Tarnobrzeg deposit was measured. In 1958, the Piaseczno open-pit mine began operations. In 1966, the experimental Grzybów borehole mine was opened. The following year, a second borehole mine – the Jeziórko – was established. In 1969, the Machów open-pit mine was launched. In 1973, the Piaseczno underground mine came on stream. Since 1985, preparatory work has been under way to open the Osiek-Baranów borehole mine.

The most important factors in the recent developments have been the rapid and accurate geological assessment of the sulphur deposits, and the government's policy of relating the development of new industries to the national raw material base. The rate and scope of geological exploration and research defined the raw material base so clearly that a comprehensive, strategic programme for the development of the sulphur industry in Poland was possible. The realization of this program has made Poland the world's fourth-largest sulphur producer, after the United States, USSR and Canada; and the world's second-largest sulphur exporter, after Canada, responsible for about 25 percent of world export trade.

[1] Throughout this text, the term "sulphur" is used to denote elemental sulphur, or brimstone, unless otherwise specified.

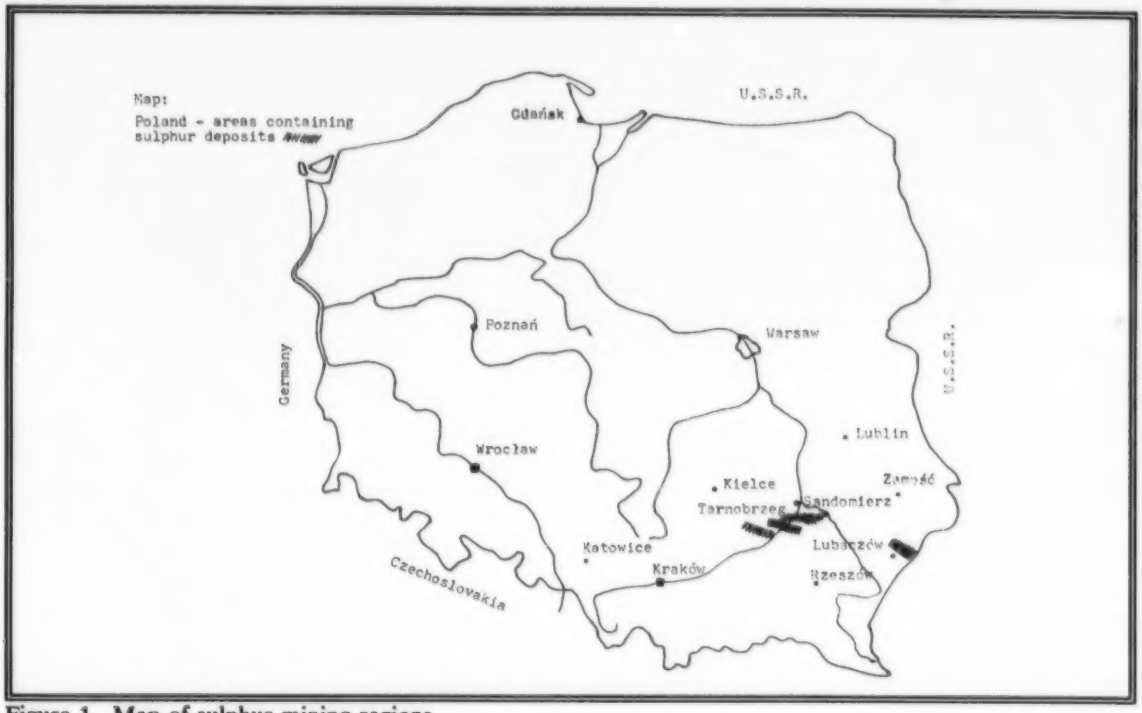

Figure 1. Map of sulphur mining regions

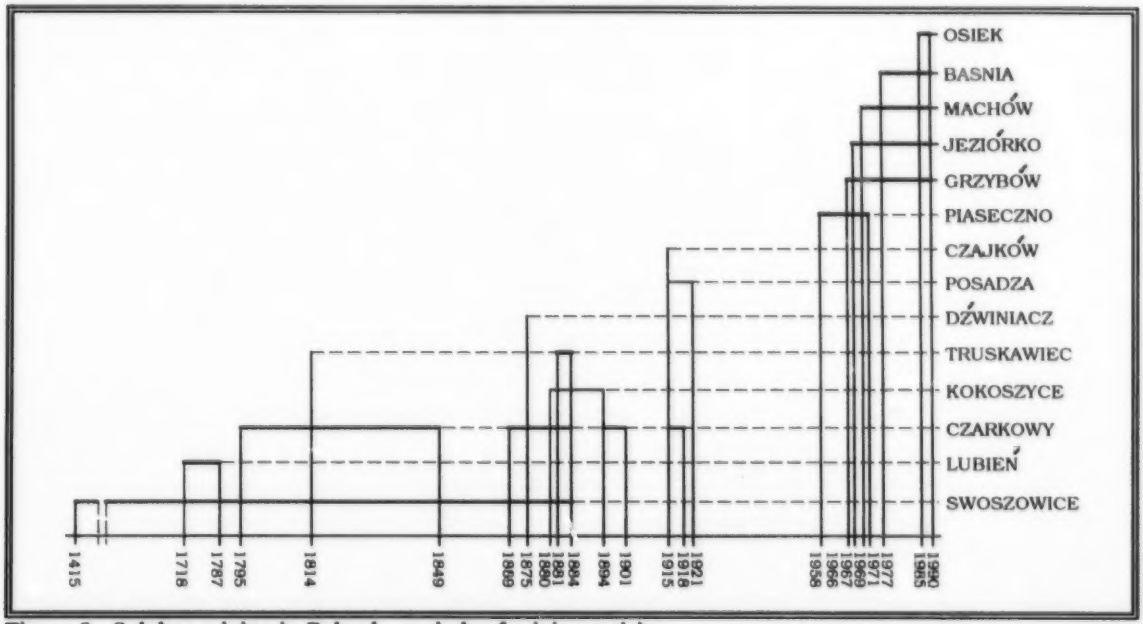

Figure 2. Sulphur mining in Poland - periods of mining activity
Source: Adapted from *Siarka* (1986), p. 48.

2. Organizational Structure of the Sulphur Industry

The organizational structure of the sulphur industry in Poland has evolved rapidly during the last 35 years. In the first period, 1955-59, the sulphur industry was controlled by the Central Association for Mining of Chemical Raw Materials in Warsaw and comprised two mines, the Staszic pyrite mine at Rudki, near Kielce, and the Nowy Lad anhydride mine at Niwnice; a processing plant for mined chemical raw materials in Ogorzelec; the Central Sulphur and Chemical Raw Materials Laboratory in Warsaw; and the sulphur operations at Tarnobrzeg, which were under construction.

The second period of sulphur industry development, 1960-68, was directed by the Mining Union for Chemical Raw Materials, based in Warsaw. During this time, the Piaseczno open-pit mine was opened up, together with the flotation plant at Machów. Construction of borehole sulphur mines at Grzybów and Jeziórko was started, as was the development of a second open-pit mine at Machów.

The third period began in 1969, with the creation of the Combine of Sulphur Mines and Sulphur Processing Plants, with headquarters at Machów. The Mining Union for Chemical Raw Materials in this period was based in Kraków and was responsible for the sulphur industry; the mining of salt, barite, anhydrite and siliceous earth; two research and development centres (in Kraków and Machów); and the investment/engineering enterprise "Hydrokop".

Since 1988, the sulphur industry Siarkopol has been under the control of the Ministry of Industry, located in Warsaw. Its basic production units are Machów (open-pit mine and processing plant), Jeziórko (borehole sulphur mine), Grzybów (borehole sulphur mine), Basznia (experimental borehole sulphur mine), Osiek, Baranów (pilot sulphur mine), Gdańsk (loading terminal), and Machów (Research and Development Centre).

3. Sulphur Deposits and Reserves

Native sulphur is easily recoverable from ore with high sulphur content; therefore very small deposits (with sulphur reserves below one million tonnes) often can be mined profitably. However, the greatest deposits have reserves of over 200 million tonnes (see Table 1). The greatest are biochemogenic deposits. These occur in only a few countries: Poland, the U.S., the U.S.S.R., Mexico, and Iraq. Numerous but rather small volcanic deposits occur in the Circum-Pacific volcanic belt, including those in Indonesia, Japan, the U.S.S.R. and Latin America.

Minable concentrations of sulphur were found in marine Miocene strata infilling the Carpathian foredeep in southern Poland (see Figure 3). None was exposed; all were covered by a thick blanket of barren strata. The mines opened since 1956 now produce close to 5 million tonnes of sulphur per year.

Exploration for sulphur in Poland began in the Tarnobrzeg area, where deposits were found in 1953, and has continued to the present in the Holy Cross Mountains and Lubaczów areas. All discoveries were in areas where glacial debris concealed the deposits, so the exploration program was based upon integrated geophysical surveys, geological studies, interpretations and drilling.

The deposits of native sulphur in Poland occur in three regions Tarnobrzeg (80.4 percent of total proven reserves), Staszów (8.6 percent of total proven reserves), and Lubaczów (11.0 percent of total proven reserves).

Mining areas of proven sulphur ore deposits, covering a total surface area of about 200 km^2, are Jeziórko (96 km^2), Machów (44 km^2), Osiek (23 km^2), Baranów (20 km^2), Grzybów (10 km^2) and Piaseczno (7 km^2).

Deposits of the Tarnobrzeg Region

The region is located between the Vistula and San Rivers and contains about 80 percent of the proven sulphur reserves of Poland. Two deposits are located there: Piaseczno-Machów-Jeziórko-Jamnica and Osiek-Baranów.

The Piaseczno-Machów-Jezióko-Jamnica deposit is probably the biggest sulphur ore deposit in the world. The Tarnobrzeg region as a whole is 35 km long and 1 to 6 km wide. In the vicinity of Piaseczno, the orebody is covered by 14.5 m of overburden; to the east and near the San River, it reaches a depth of 280 m. The thickness of the deposit is about 0.5 to 1.0 m. The average sulphur concentration is 27 percent and ranges from 10 to 55 percent. The chemical composition of the sulphur ore varies.

The Osiek-Baranów deposit is located 6 km south of the deposit described above, and is 18 km long and up to 1.5 km wide. The Vistula River Valley divides the deposit into two parts: Osiek and Baranów. The deposit thickness ranges from 10 m to 46 m, and the sulphur content is 10 percent to 24 percent. The depth of the lens drops from 100 m to 264 m toward the east.

Deposits of the Staszów Region

This sulphur-bearing region is located in the southwest part of the Tarnobrzeg voivodeship administrative district and contains 29 percent of proven domestic reserves. The Grzybów borehole mine is now active, and it yields 17 percent of Poland's production. However, the Grzybów reserves are nearly exhausted, and a new Osiek-Baranów borehole mine is under construction in this area.

Table 1. Size of native sulphur deposits

Size of Deposit	Sulphur reserves (million tonnes)	Examples of Various Sizes	Economic Importance
Exceptionally great	over 200	Machów-Jeziórko (Poland) Osiek-Barandów (Poland)	Main source of native sulphur in international trade
Very great	100-200	Basnia (Poland) Mishraq (Iraq)	
Great	20-100	Grzybów (Poland) Ruster/Springs (U.S.) Jaltipan (Mexico)	
Medium	5-20	Pomezia (Italy) Texistepec (Mexico)	Source of native sulphur for internal use, partly exported
Small	1-5	Keciborlu (Turkey) Rotokaua (New Zealand)	
Very small	0.2-1	Swoszowice (Poland) Scilian (Italy)	Occasionally mined for local use
Occurrences	below 0.2	Posadza (Poland)	

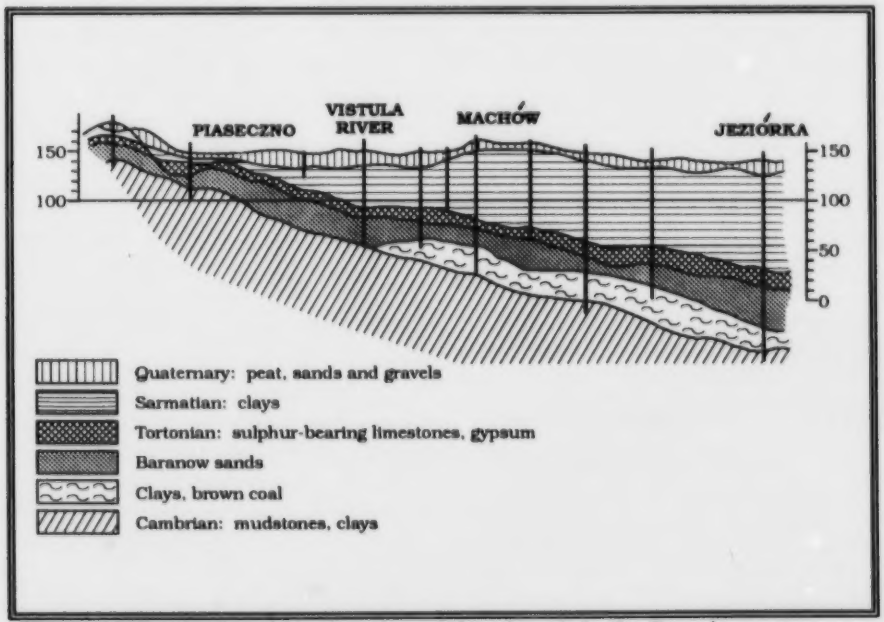

Figure 3. Cross-section through native sulphur deposit in the Tarnobrzeg area

The medium-sized Grzybów deposit forms elongated lenses running northwest-southeast, with a maximum width of 0.2 to 1.4 km and a length of 12 km. The overburden is 20 m in the westerly direction and 200 m to the east. The thickness of the deposits varies by as much as 45 m, and concentration varies from 17 percent to 27 percent. Native sulphur appearing in the ore has a crystalline, waxy or dusty structure, and a pocket, braccia and veined texture.

The Grzybów deposit was recognized as extremely attractive, for its thickness and the isolation of the sulphur-bearing layer. In 1956 the Geological Institute evaluated this deposit using an experimental underground smelting method, and development was undertaken in 1966. This was the first application of this method in Europe, and it has since been applied successfully in other mines.

After years of technological testing and experiments, the Grzybów mine reached a production scale of 1.2 million tonnes a year, a considerable achievement in comparison with similar enterprises worldwide. In 1979, production of carbon disulphide was added, expanding the products available to local and international markets.

Deposits of Lubaczów Region

The sulphur-bearing Lubaczów region in the Przemysl voivodeship stretches towards the U.S.S.R. border. There is no connection between this region and those previously mentioned. This fact is important, taking into consideration ecological and hydrogeological aspects of sulphur mining development.

The Basznia deposit is the western end of the Niemirów deposit in the U.S.S.R. To date, examination of a 13-km orebody of the Basznia deposit indicates that it extends northwest, submerging to 245 to 350 m. The thickness of the sulphur-bearing limestone varies from 0.2 m to 32.2 m (the average is 11.7 m). The sulphur content in the limestone reaches 32 percent. The deposit has great potential for the economy of Poland, and an experimental well is being developed to exploit a portion of it.

In June 1990, during the 2nd World Investors Forum held in Warsaw, an agreement was signed to create Sulphurguest of Poland (a joint venture involving a US partner which contributed capital of $100 million) for the further exploitation of the Osiek-Basznia mine. The same US firm has already received approval from the Ukrainian government to develop the part of the Niemirów deposit that lies within the Soviet Union.

Chemical and Mineral Composition of Sulphur Ores

Most rock is limestone, but marl and clay occur in lesser amounts. Analytical data of limestones show that their average composition is 62.9 percent calcium carbonate, 26.5 percent sulphur, 10 percent other material ($Si0_2$, $A1_20_3$, Fe_20_3, Mn0, Sr0, Ba0, $CaS0_4$, K_20, Na_20) and 0.5 percent bitumens.

Accessory minerals accompanying sulphur include calcite, aragonite, celestite and barite. Openings lined with druses of crystalline sulphur also contain crystalline calcite and celestite. Metallic trace elements are widespread in sulphur. During the spectral analyses of postgypsum limestone, 11 elements were found to occur: Zr, Cr, Mo, Co, Ni, Cu, Ag, Zn, Sn, Pb and Ga. The average results of many analyses showed that Cu, Cr, Ni, Pb, Mo, and Ga occur in the largest quantities, whereas arsenic and selenium are known only in local traces. The sulphur content of minable blocks ranges from about 26 percent to 30 percent.

4. Sulphur Mining

Three different methods are applied in sulphur mining: conventional underground, open-pit, and underground melting. Two methods – open-pit mining with flotation refining and the borehole method of underground melting – are the basic systems in use. The older conventional underground mining methods are now applied only when the other two methods are unsuitable. Currently, about 88 to 90 percent of sulphur recovered from native sulphur deposits in Poland is obtained by underground melting. Mining accounts for the balance, with 8 to 12 percent recovered from open-pit mining and only 1 to 3 percent by conventional underground mining methods (see Tables 2 and 3). The mined sulphur is then recovered from the ore by concentration and refining.

Conventional Underground Mining

Conventional underground mining is seldom used because of its relatively high costs and related technical problems. The main difficulties are caused by underground water which is often rich in H_2S and sometimes very hot. The presence of poisonous H_2S requires well-ventilated underground workings. Underground mining is, however, the only method applicable when open-pit mining or underground melting are impossible, for example with steeply inclined deposits with surface outcrops. Various stoping methods are applied, including room and pillar, cut and fill, shrinkage, and short wall. Mined high-grade ores (over 30 percent sulphur) are sent directly to the refinery without further treatment. Low-grade ores are concentrated by flotation and then refined.

Open-pit Mining

Open-pit mining is used for deposits at shallow depths, below thin, easily workable overburden. The pits range in size from very small surface strip mines, in the case of sublimation deposits, to deep mines, in the case of strata-bound biochemogenic deposits which can yield up to hundreds of thousands of tonnes annually.

Table 2. Poland - sulphur mining by method of exploitation 1961-1989

Year	Sulphur Production (100% S) 000 tons	Open-pit Method (%)	Borehole Method (%)
1961	133	100.0	--
1962	210	100.0	--
1963	235	100.0	--
1964	295	100.0	--
1965	431	100.0	--
1966	633	97.5	2.5
1967	912	65.4	34.6
1968	1,548	38.7	61.3
1969	1,942	28.1	71.9
1970	2,780	29.9	70.1
1971	2,713	18.8	81.2
1972	2,927	20.7	79.3
1973	3,545	18.9	81.1
1974	4,093	11.4	88.6
1975	4,771	10.5	89.5
1976	4,891	12.8	87.2
1977	4,765	9.5	90.5
1978	5,051	12.3	87.7
1979	4,830	6.0	94.0
1980	5,164	8.6	91.4
1981	4,722	4.8	95.2
1982	4,935	6.5	93.5
1983	4,999	10.8	89.2
1984	4,990	12.3	87.7
1985	5,876	13.4	86.6
1986	4,866	10.9	89.1
1987	4,938	13.4	86.6
1988	4,968	13.2	86.8
1989	4,832	13.0	87.0

Table 3. Poland - sulphur production by mine 1975-1989 (percent)

Year	Machów Open-pit Mine	Jeziórko Borehole Mine	Grazbów Borehole Mine	Basznia Borehole Mine
1975	10.5	63.1	26.4	-
1976	12.8	57.6	29.6	-
1977	9.5	60.0	30.5	-
1978	12.3	59.2	28.5	-
1979	6.0	64.7	29.3	-
1980	8.6	63.4	28.0	-
1981	3.3	67.4	29.3	-
1982	7.2	65.4	27.4	-
1983	9.9	66.8	23.3	-
1984	10.7	67.9	21.4	-
1985	12.4	68.4	19.2	-
1986	10.9	69.3	18.9	0.9
1987	13.4	68.4	17.6	0.6
1988	13.2	68.2	17.5	1.1
1989	13.0	68.2	17.7	1.1

Source: *KIZPS Siarkopol.*

The open-pit method involves the following operations: dewatering of overburden and deposit; removal of overburden; dumping of overburden; brimstone exploitation; and ore flotation. Ore treatment is the same as in the case of conventional underground mining.

Underground Melting

A considerable proportion of the sulphur lies at depths below the surface which make open-pit mining uneconomical. It was, therefore, necessary to evaluate the feasibility of an underground melting technique. There was some doubt as to whether the underground melting method could work in the deposits in Poland, where, in contrast to those worked by the standard Frasch technique, parts of the orebody are not spatially isolated.

To solve this problem, an underground melting system was developed and tested which introduced innovative technology to overcome specific local problems. Next, studies were made of the flow of groundwater within the deposits, in order to optimize the directed flow of the heated water for sulphur melting.

Additional innovations included a method of reworking mining areas used in the experimental period, allowing improved recoveries, and optimization of the feed for the exploitation boreholes and the hot water consumption per tonne.

These innovations have made the borehole method of exploitation currently in use economically and technically feasible. Although developed for the specific geological situation found in Poland, this "Polish Method" could be applied wherever sulphur deposits which vary in permeability are found. Because the method is economical and employs uncomplicated equipment which can be erected quickly, investment costs can be recovered rapidly.

Losses in Sulphur Mining and Processing

Losses occur in all stages of sulphur recovery. There are different causes of sulphur loss, depending upon exploitation methods, processing, structure of deposit, etc. Although some losses are possible to predict in a feasibility study, real losses often exceed the predictions. Some losses are the result of random factors: for example, borehole failure or incomplete extraction. These losses could be minimized by more efficient operating techniques. Further losses occur during sulphur processing and refining. Distribution of the sources of loss is shown in Table 4.

In open-pit mines, mining losses are as high as 10 to 20 percent and are caused by technological and geological factors, as well as by adhering in dewatered deposits. About 20 percent of sulphur is lost during processing. Most of the lost substance is contained in post-flotation wastes. Some losses are connected with storage.

Table 4. Losses in sulphur mining and processing (percent of proven reserves)

Kind of Losses	Recovery Method	
	Open-Pit	Borehole
Total losses[a]	25-30	30-50
Mining		
at deposit floor	2-6	5-10
non-metallic sulphur	-	25-40
others	3-10	5-10
total	5-14	30-50
Processing	17-20	1

Source: *Siarka*, 1986.
[a] without pillar losses. In Poland this is assumed to be about 17 percent.

In borehole mines, the largest losses occur at the mining stage; a large amount of sulphur remains at the deposit floor and additional loss occurs in the melting zone due to "non-meltable" sulphur. In addition, in the borehole method applied in Poland, high losses are related to eruptions, i.e. unexpected waters outflows caused by borehole column failure.

A broader defintion of losses, related to natural environmental devastation by sulphur mining, is discussed in Chapter 6.

5. Commercial Sulphur Products

Sulphur produced by both open-pit and borehole mining is marketed in the following forms:

Liquid sulphur is the basic traded product and accounts for 40 percent of total sulphur production. It is produced in three grades as specified in Polish Standard PN-70/C-84083:

- modification 9995 has 99.95 percent S and 0.05 percent impurities;
- modification 9990 has 99.90 percent S and 0.10 percent impurities;
- modification 9985 has 99.85 percent S and 0.15 percent impurities.

Liquid sulphur is a raw material used for the production of sulphur in other marketable forms. It is used within Poland for the manufacture of sulphuric acid, carbon disulphide and hydroxylamine sulphate, and is the principal sulphur export product.

Lump sulphur is similarly produced in the three grades, 9995, 9990 and 9985. Currently, sulphur produced in lump form accounts for about 50 percent of total output. It is used for the production of sulphuric acid, dyestuffs and other chemicals. Because of its potentially adverse effect on the environment during handling, lump sulphur is being replaced steadily as an export product by liquid, granulated and flake sulphur.

Granulated sulphur is again produced in the three grades defined by the standard. The product, made by cooling liquid sulphur droplets in a counter-current air stream according to a process developed in Poland, is about 90 percent granules of diameter 0.5 to 3.2 mm and about 10 percent with diameter 0.5 mm.

This product is used within Poland by the sugar industry, for pharmaceuticals and cosmetics, and in the textile industry. Granulated sulphur is preferred by those users of solid sulphur who wish to minimize the dust problem. It is also an important export, accounting for about 10 percent of total sulphur export sales.

Sulphur flakes are produced in the three grades, as irregular, slatey flakes.

Powder sulphur is produced in the three standard grades, with the 9985 analysis being available in three variants. Poland's consumption takes up about 50 percent of total output, with the rubber industry using 36 percent.

Oil sulphur is produced by adding from 3 to 4.5 percent of paraffin to powder sulphur. This is a dust-free product.

Sublimed reagent sulphur is produced in two qualities according to Polish Standard BN-65/6191-34, as sublimed pure sulphur. The output of sublimed sulphur is consumed by the domestic reagent industry.

Crystalline reagent sulphur is also produced in two qualities, according to Polish Standard BN-65/6191-35, as crystalline pure reagent sulphur with 99.98 percent sulphur and 0.02 percent ash, and as crystalline pure sulphur with 99.95 percent sulphur and 0.05 percent ash. Total production amounts to 3 tonnes (100 percent S) per year and is used in the manufacture of chemical reagents.

Sulphur in sticks is solid sulphur cast in round sticks and produced in three qualities, according to Polish Standard ZN-71/MPChem/S-2:

- modification 9995 has 99.95 percent sulphur and 0.05 percent ash;
- modification 9990 has 99.90 percent sulphur and 0.1 percent ash;
- modification 9985 has 99.85 percent sulphur and 0.15 percent ash.

Total production is about 6,000 tonnes (100 percent S) per year and is used in the control of pests in horticulture and viticulture.

The existing program of sulphur processing in Poland does not, however, exhaust all the possibilities. The range of forms produced for sale – including granulated sulphur, flake sulphur, powder sulphur, and the low-volume reagent grades – do not represent a complete exploitation of possibilities for sulphur utilization. In view of the international trend towards upgrading of sulphur to higher-quality products, Poland plans to develop a wider range of marketable sulphur products. New products will include insoluble sulphur, precipitated sulphur, and sulphur modified by polymers, and the production of sublimed sulphur will be intensified.

Independent of the production of new marketable forms of sulphur, it is also anticipated that large-scale, new applications for sulphur may be developed within the building and construction industry, such as foamed sulphur insulation, sulphur concrete, sulphur binders and sulphur-asphalt mixes for road paving. These applications are under active investigation by a number of research groups, and Poland's industry is following the progress with interest.

Within Siarkopol, the state sulphur monopoly, the Research and Development Centre for Sulphur Industry operates in Machów. In addition to research and implementation work, the Centre produces purified sulphur forms: sublimed sulphur, lac of sulphur,[2] spectrally clean sulphur, biosulphur RT, and colloidal sulphur (now being tested). Other forms of sulphur production are possible; however, their development is constrained at present by the lack of sufficient markets for these products which require expensive modern equipment.

The Centre could produce enough of these to meet domestic demands and export surplus. Biosulphur RT, also called liquid organic sulphur, is biologically pure. It contains about 99.99 percent S. Because of its purity and properties, it is used mainly in the production of cosmetics, shampoos, creams, tonics, etc. Sublimed sulphur, also called "sulphur flower", is a bright yellow powder of extremely high purity. Two kinds – for colour TV kinescopes and as a chemical reagent – are produced.

[2] Widely used in the pharmaceutical industry. Biosulphur RT and sublimed sulphur deserve special mention.

6. Environmental Protection

Poland is one of the areas in Europe most subject to high levels of sulphur dioxide pollution. The average annual sulphur fallout in Poland is 6 tonnes/km^2; in the southwestern part of Poland, it amounts to 12 tonnes/km^2. It is estimated that about 50 percent of sulphur deposition originates outside of Poland.

The sulphur components of gas emissions, wastes and sewage, so dangerous to the natural environment, can be recovered if the appropriate technology is used. For example, Canada, Poland's most important competitor in the international sulphur market, has been compelled by environmental regulation to produce elemental sulphur as a by-product of natural gas.

The sulphur region in Poland is a region of concentrated mining, mineral processing, and chemical technologies. Although intensive development of the sulphur industry in Poland has proven profitable for the regional and national economies, it has caused extensive environmental damage to water, air and soil. The sulphur industry's environmental impact on the Tarnobrzeg area is presented below and compared to the total impact of all sources of pollution (i.e. sewage, air pollution and industrial waste).

Surface Waters Pollution

The sulphur industry is very water-intensive. Table 5 presents the volumes of sewage discharged into surface waters.

The Vistula River is polluted by sulphur industry waste both directly and indirectly. Industrial sewage from mining operations, as well as rainfall and water from quaternal and tertiary, drain directly into the Vistula. Considerable amounts of pollution come from indirect inflows of two small rivers containing mining waters from the Machów and Jeziórko mine deposits. Of the total sewage effluent from the sulphur industry drained to surface waters, only 7.5 to 11 percent is clean.

Underground Waters Pollution

Water is scarce in the Tarnobrzeg region; about 40 percent of the territory experiences a water deficit. Particularly important is the shortage, in terms of both quantity and quality, of underground water reserves within urban areas, which necessitate costly projects of long-distance (10 to 20 km) transportation of fresh water.

Dewatering of sulphur mines is the principal problem in sulphur mining. The rate of dewatering affects the volume of mining waters released to the surrounding area. A growing degradation of waters flowing from quaternary and tertiary rocks has occurred in the vicinity of the sulphur mines. Although this water has been used for communal purposes in the past, it is now too polluted by sulphur compounds.

Table 5. Amount of industrial sewage (million m^3/year) surface waters in Tarnobrzeg region 1980-86

Year	Sulphur Industry (million m^3/year)	Total	% of Total
1980	94.7	144.0	65.8
1981	98.9	140.3	70.5
1982	86.2	140.9	61.2
1983	98.8	130.4	75.8
1984	97.0	131.2	73.9
1985	91.3	119.1	76.6
1986	89.4	128.6	69.5

Source: *Grzmil* (1987), p. 11.

Air Pollution

The following industrial activities are sources of air pollution in the Tarnobrzeg area:

Industry Activity or Production of	Produces Resulting Pollutants
sulphuric acid	SO_2, SO_3 and H_2SO_4
superphosphate	fluorine compounds
cryolite	dust
mining water treatment	H_2S and dust
bleached clay	H_2S and dust
sulphur purification	sulphur dust
heating plants	NO_x and SO_2

In the sulphur industry, the impact of "disorganized emissions" on air quality is of great importance. This kind of emission is especially noxious in the immediate vicinity of the emissions. Disorganized emissions include hydrogen sulphide emission, sulphur self-ignition, leakage of sulphur, dusts from processing, storage, loading and transportation. It is difficult to estimate the volume of these disorganized emissions.

Soil Contamination

The sulphur basin covers 39 km^2, of which 90 percent is farming and forest land. Water and air pollution affect the soil, plants and forests, greatly contaminating and acidifying the land and reducing its productivity. Sulphur contamination leads to increased concentrations of sulphur and of hydrolytic acidity. The most alarming changes occur close to emission sources, and are especially severe in the sandy soil which is predominant in the region and very susceptible to degradation.

Sulphur mining endangers the forest areas, as well. Forests constitute 29 percent of the region. Surface exploitation requires deforestation. In addition to the sulphur contamination, this reduction in forested area reduces the vitality and immunity of the remaining forests.

Land Reclamation

Sulphur mines and plants take up about five thousand hectares of land (see Figure 4).

The areas affected by mining productivity are predominantly arable land. Throughout the time span of mining operations, 80 million tons of sulphur have been produced, and 258 million cubic metres of overburden mass removed and dumped. In the process, 340 farms were eliminated. Only 600 hectares have been reclaimed and turned back to farming, about 10 percent of the area which was taken over.

The real environmental losses resulting from 35 years of sulphur industry activity in Poland are still unknown. Environmental protection problems are fundamentally economic. The huge costs must be borne, and it is crucial to find the appropriate financial sources to meet these demands, as well as effective policy instruments to allocate the costs and minimize the environmental damage.

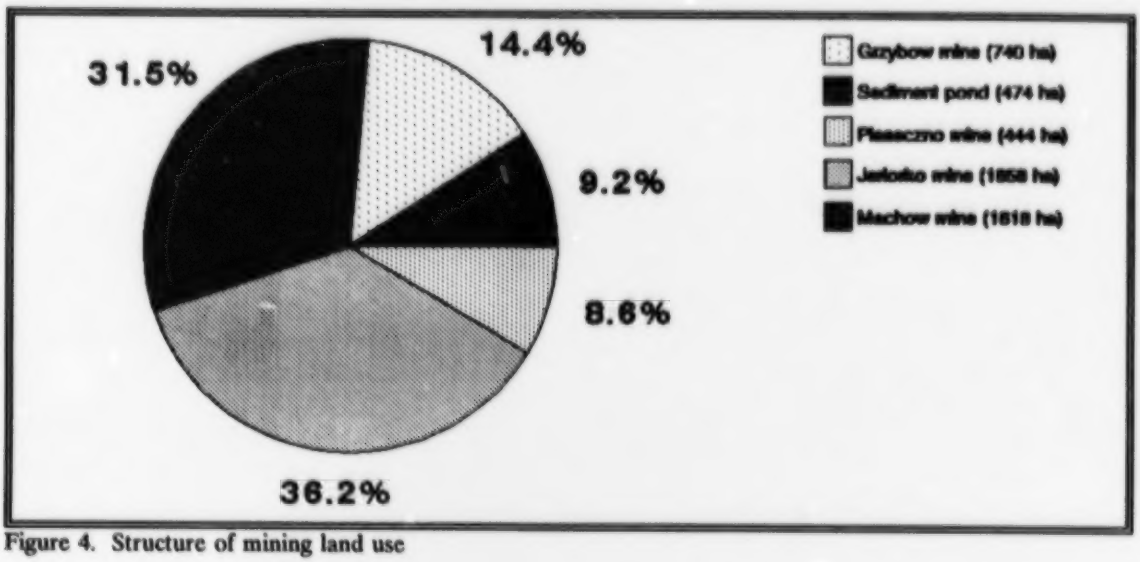

Figure 4. Structure of mining land use

Table 6. Air pollutants (controlled emissions) from sulphur industry and sulphur emissions from all sources in Tarnobrzeg region 1980-86

Year		Pollutants (tonnes/year)					
		Dust	SO_2	NO_x	F	H_2S	H_2O_4 and SO_3
1980	A	11,904	11,763	70	35	86	1,251
	B	79,163	81,219	730	36	126	1,252
1981	A	7,362	9,533	38	35	107	712
	B	66,552	140,036	494	36	258	713
1982	A	5,405	7,041	70	35	39	485
	B	87,800	161,500	970	36	221	485
1983	A	4,521	5,754	33	107	12	512
	B	70,900	210,300	28,000	107	100	512
1984	A	4,796	4,341	27	125	5	351
	B	55,000	224,948	25,425	125	34	351
1985	A	4,380	7,477	67	51	3	446
	B	56,469	191,581	26,900	300	35	446
1986	A	2,667	8,796	203	81	2	440
	B	53,220	202,940	19,485	285	109	441

A - Sulphur industry emissions.
B - Sulphur emissions from all sources in Tarnobrzeg region.
Source: Grzmil (1987), pp. 21-22

7. Sulphur Product Exports

Poland as a Sulphur Exporter

Import and Export of Chemicals Limited (Ciech) in Warsaw is the Polish state agency engaged in the trade of chemical products. Within Ciech, a special department, Siarkopol, has been responsible for sulphur product exports since it was established in 1961.

Sulphur exports have been significant to the economy of Poland, as the following points emphasize:

- sulphur is second only to hard coal in terms of export value;
- Poland contributes about 20 to 25 percent of world sulphur exports;
- in total, 62 million tons of sulphur have been exported from Poland since 1961.

Poland's export activities in sulphur products to date can be divided into four periods:

- 1961-67: entered into international markets;
- 1968-73: dynamic growth in exports – became the world's second-largest exporter of sulphur, after Canada;
- 1974-89: stabilization of Poland's position as the world's second-largest exporter of sulphur;
- 1990-: changes in the geographical destinations of Poland's sulphur product exports, as a result of changes in the payment system within Comecon, and the transition of Poland's economy from central planning to a market economy system.

Table 7 presents brimstone exports by countries and world total in 1989. Since 1960, the following phenomena have been noted in the world sulphur markets:

- a four-fold increase in sulphur trade turnover (from 3.7 million tons in 1960 to 18.2 million tons in 1987);
- domination of the five largest exporting countries (Canada, Poland, Mexico, the U.S. and France);
- reorientation of sulphur product exports (West Europe and North America lost their previous domination of the growing export trade in sulphur to Africa, Asia and East Europe).

Table 7. Leading world brimstone suppliers production and exports, 1987 (thousand tons)

Country	Production	Exports
United States	10,398	946
U.S.S.R.	6,640	n.a.
Canada	5,830	5,791
Poland	4,865	3,653
Mexico	2,012	1,130
Saudi Arabia	1,500	939
Iraq	1,400	1,389
West Germany	1,326	670
Japan	1,176	250
France	874	410
Kuwait	560	540
Iran	460	330

Source: British Sulphur Corporation; *SulpAur*, No. 210, September-October, 1990.
n.a. - not available

Destination of Polish Sulphur Exports

From 1960 to 1989, sulphur products have been exported to various markets with different payment systems (i.e. to Comecon and market economy countries). During this period, the total volume of exports and the distribution between these two groups of countries have been relatively stable (see Table 8). However, the terms of payment are different. With Comecon, payments have been in rubles, but with market-economy countries, payments have been in US dollars. Table 9 includes the value of sulphur product exports with prices in rubles and US dollars.

The price policy for sulphur exports to Comecon is an important and growing problem in Poland, one that is causing increasing concern. It has been pointed out in many reports that the pricing system for sulphur exports to Comecon is inefficient, and that only the provision of central budget subsidies has maintained minimum profitability in the industry.

Table 8. Poland's sulphur exports, 1980-89 (thousand tons)

Year	Total thousand tonnes	Comecon countries % of total	Market economy countries % of total
1980	2,582	44.9	55.1
1981	2,637	34.3	67.7
1982	2,827	35.8	64.2
1983	2,957	38.6	61.4
1984	3,157	38.2	61.8
1985	3,130	39.3	60.7
1986	3,020	38.7	61.3
1987	3,097	42.5	57.5
1988	3,120	37.7	62.3
1989	2,883	41.8	58.2

Source: *KIZPS Siarkopol.*

Table 9. Poland's sulphur export values[a] and unit values 1980-89

Year	Export Values Million Rubles	Export Values Million $US	Unit Values Million Rubles	Unit Values Million $US
1980	56.8	138.0	48.8	97.3
1981	49.8	221.7	55.0	128.0
1982	68.8	215.1	68.0	118.4
1983	91.9	183.1	80.6	100.8
1984	107.7	207.2	89.3	106.2
1985	116.6	265.9	94.7	140.1
1986	125.8	257.2	107.7	138.9
1987	143.5	189.2	109.1	106.2
1988	132.9	193.7	112.9	99.7
1989	137.5	170.3	114.1	101.5

Source: *KIZPS Siarkopol.*
[a] Current delivered values.

In 1988-1989, the contracted prices without Comecon – without subventions – were about four times lower than the prices for sulphur exported to market-economy countries. An artificially high exchange rate for rubles in terms of convertible currencies is one of the reasons for this problem.

The cost of producing one tonne of sulphur over the period 1988-89 averaged 400 thousand Polish zlotys. As a result, each tonne exported to Comecon meant a loss to Polish mines of 150 thousand zlotys.

The significance of this calculation is even more alarming in view of the fact that Poland must import some necessary equipment from the West (e.g., drilling pipes, fittings, heavy mining equipment, etc.), which burdens each tonne of sulphur produced with a cost of US$4. To complete the calculation, it is necessary to add that Poland, thanks to sulphur exports to the U.S.S.R., gets Soviet natural gas at world price levels.

Prices of sulphur products exported to market- economy countries are based on the laws of supply and demand, determined by business cycles. At present, Poland's sulphur exports are more transparent and realistic due to the recent introduction of convertibility of Polish currency, and to stagnation in international sulphur markets. Although costs of production have increased, reducing profitability, Poland's sulphur product exports to western markets continue to be profitable.

The history of Poland's sulphur exports shows that the prices of exports to market economy countries have not always covered the cost of production, as they did in 1970, but in some years Poland sold sulphur for higher prices than competitors (see Table 10).

In 1988, the profitability of Poland's sulphur exports was 106.7 percent; in 1989 this figure rose to 150.3 percent. In 1990, however, only 66.7 percent is expected.

Tables 11 and 12 include prices in US dollars for Polish sulphur. It can be noted that Poland has been the main sulphur supplier for Comecon, and a traditional exporter to Western European and North African countries.

Table 10. Contract prices, 1982-90 (US$/t)

Year	Canada FOB Vancouver	Poland FOB Gdansk	U.S. FOB Gulf of Mexico	Middle East FOB Persian Gulf
1st half 1982	100-113	125-140	125-135	123-130
2nd half 1982	110-113	115-120	110-115	112-120
1st half 1983	92-100	105-115	108-110	100-108
2nd half 1983	83-86	100-105	85-95	93-96
1st half 1984	85-87	100-105	85-95	94-98
2nd half 1984	105-110	118-125	105-110	116-125
1st half 1985	125-135	138-145	125-135	147-155
2nd half 1985	135-145	150-155	135-140	148-150
1st half 1986	135-139	144-150	134-136	133-136
2nd half 1986	125-135	135-145	130-136	120
1st half 1987	98-110	110-113	95-107	100-107
2nd half 1987	90-100	97-100	95-100	95-100
1st half 1988	90-98	96-99	99-105	97-100
2nd half 1988	98-105	102-105	105-110	100-104
1st half 1989	105-113	110-118	110-115	95-105
2nd half 1989	80-95	100-120	79-85	81-90
1st half 1990	79-88	88-100	88-94	81-90
2nd half 1990	90-95	93-104	100-105	85-90

Source: *Sulphur*, various years.

Table 11. Poland's sulphur export prices by country of destination ($US) 1980-1985

Country	1980	1981	1982	1983	1984	1985
Bulgaria	41.0	52.0	69.0	79.0	87.4	89.8
Czechosolvakia	69.0	56.0	67.4	82.4	91.2	91.7
Korea PDR	41.0	52.0	65.5	76.4	82.4	91.0
Mongolia	-	98.5	98.5	-	-	-
GDR	47.0	59.3	71.1	84.6	94.9	94.9
Romania	53.0	50.4	62.8	78.5	90.1	87.3
Hungary	43.0	56.5	70.9	83.3	93.1	98.3
Vietnam	72.0	103.2	135.4	155.0	165.0	133.9
Cuba	140.0	97.4	155.4	114.5	-	-
U.S.S.R.	48.0	51.8	65.0	76.4	84.5	93.4
Argentina	-	115.4	198.0	-	-	-
Austria	218.0	78.8	168.1	158.3	107.9	158.3
Bangladesh	-	-	116.6	104.0	98.5	-
Belgium	90.0	115.4	127.9	108.2	106.0	136.0
Brazil	111.0	131.3	122.3	101.8	105.3	136.0
Cyprus	154.0	226.0	192.8	145.0	132.9	249.0
Denmark	188.0	202.0	205.8	205.8	20.10	249.0
Finland	120.0	141.4	112.6	118.3	115.1	150.7
FR Germany	83.0	72.0	103.2	101.4	97.7	121.7
France	86.0	132.7	161.8	103.3	165.4	118.4
Greece	115.0	70.9	83.0	97.3	108.2	146.8
Holland	85.0	119.0	125.9	99.7	105.5	125.9
India	115.0	127.0	-	143.3	145.7	146.0
Italy	104.0	155.0	124.5	106.0	117.1	144.8
Jordan	-	-	117.7	-	-	-
Kenya	162.0	190.0	132.8	167.0	116.7	179.6
Malaysia	162.0	172.0	178.0	-	-	-
Morocco	107.0	129.7	119.0	98.7	104.8	139.7
New Zealand	-	-	186.0	-	-	-
Pakistan	169.0	178.9	185.0	-	-	-
Paraguay	-	-	227.0	-	-	-
Portugal	105.0	147.5	-	-	-	-
Spain	126.0	125.0	120.0	-	-	-
Sweden	103.0	100.9	134.4	112.9	119.3	154.7
Thailand	161.0	189.0	181.3	173.1	139.7	159.2
Tunisia	115.0	132.0	133.0	92.0	100.9	140.4
Turkey	130.0	-	-	-	-	-
United Kingdom	121.0	139.5	119.8	99.4	100.6	129.4
Yugoslavia	106.0	135.8	129.4	116.0	122.2	161.3

Source: *KIZPS Siarkopol.*

Table 12. Poland – sulphur product exports, 1988-1990 (thousand tonnes)

	January-December		
	1988	1989	1990
World Total	3,857	3,636	3,814
Western Europe	1,152	940	830
Austria	39	34	12
Belgium	3	1	1
Finland	25	30	11
France	345	258	276
Germany	314	205	100
Greece	116	102	108
Italy	53	39	78
Netherlands	27	12	6
Norway	-	1	-
Sweden	14	16	14
Switzerland	9	-	-
United Kingdom	207	244	224
Africa	462	297	851
Morocco	337	150	587
Nigeria	-	-	4
Tunisia	125	148	260
Asia	95	241	357
India	89	239	355
Singapore	-	1	1
Vietnam	6	1	-
Middle East	18	-	-
Jordan	18	-	-
South America	430	350	335
Brazil	430	350	335
Eastern Euope	1,700	1,809	1,442
Bulgaria	61	37	17
Czechoslovakia	475	415	401
Hungary	149	140	46
Romania	114	193	153
Soviet Union	748	936	720
Yugoslavia	153	87	107

Source: *Sulphur*, no. 213, March-April 1991.

Poland's sales of sulphur to Western European countries amount to about 40 percent of its total exports with sales to North African countries constituting about 20 percent. Through special trade agreements with Poland, Brazil and India are important buyers of Polish sulphur.

In the 1960s, sublimed sulphur was the prevailing export product. In the late 1960s, Poland began to export liquid sulphur, which now conprises over 25 percent of total Polish sulphur exports.

The main buyers of Polish sulphur products are large chemical firms in the United Kingdom, France, Holland and Belguim.

Several projects have been undertaken in Poland to ensure regular and reliable delivery: the construction of a terminal for liquid sulphur in Gdańsk (for 30 thousand tons); the construction of four tanker ships for liquid sulphur; and the leasing of terminals for liquid sulphur in Runcorn (England), Rotterdam (Holland) and Rouen (France). Such activities have led to the establishment of a stable set of Western European buyers.

The Situation in 1990

According to the plan for 1990, Siarkopol should export about one million tons of sulphur to Comecon. Based on previous terms of payment, this could mean great losses and nearly total bankruptcy for Polish sulphur mines.

In the current financial situation, it means that for one tonne of sulphur, Comecon should pay 110 rubles. At the rate of 2100 zlotys for one ruble (compared to 9500 zlotys for one US dollar), Poland should receive 250 thousand zlotys per tonne. But for one tonne of sulphur sold on world markets, Poland could get about US$90, or 855 thousand zlotys per tonne, or a comparable price on the domestic market. High domestic prices are possible because of the transition from a central planned economy to a market economy system now being introduced in Poland.

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